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GENERAL PRINCIPLES CONCERNING THE REACTION OF THE ORGANISM TO THE COMPLEX ENVIRONMENTAL FACTORS EXISTING IN SPACECRAFT CABINS

*by A. V. Lebedinskiy, S. V. Levinskiy,
and Yu. G. Nefedov*

*Paper presented at the XV International Astronautical Congress,
Warsaw, September 7-12, 1964*



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Translation of "Obshchiye zakonomernosti reaktsiy organizma
cheloveka na kompleksnoye vozdeystviye faktorov sredy,
kharakternykh dlya kabiny kosmicheskikh letatel'nykh apparatov"

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The problem of studying the system of the reactions of the human organism which take place under conditions of prolonged confinement in a hermetically sealed space of restricted volume has recently assumed an urgent importance in connection with various fields of human activity. It should be emphasized that the solution of this problem is facilitated by the possibility of organizing various experiments with the participation of human beings under laboratory conditions simulating the conditions of certain environmental media.

As a model for the solution of general problems, chamber tests were carried out lasting from 10 to 120 days, in the course of which a study was made of the medium forming in the chamber as a result of the vital activity of man and of his reactions under these conditions. Moreover, certain other effects were also simulated in these experiments: small doses of ionizing radiation, periodic rises in temperature, noise, and other factors.

In a hermetically sealed space, the relations between man and his ambient medium are somewhat different from those which prevail in everyday life. Whereas under ordinary conditions the vital processes of the organism depend mainly on the influence of the medium, in a hermetically sealed space the reverse dependence begins to be clearly manifested, i.e., the dependence of the changes in the medium on the vital processes of the organism. Thus, man under these conditions becomes the forming element in relation to the changes in the medium, and it should be emphasized that these changes may be undesirable in character.

This may be illustrated by several concrete examples.

An analysis of the changes in the nonspecific immunoreactivity of the subject and a comparison of these data with the changes in the microflora of the ambient medium established an appreciable increase in the number of microbes per unit volume of air. The cause was an appreciable increase in the number of micro-organisms vegetating on the skin as a result of a drop of its bactericidal function (S. N. Zaloguyev, Figure 1).

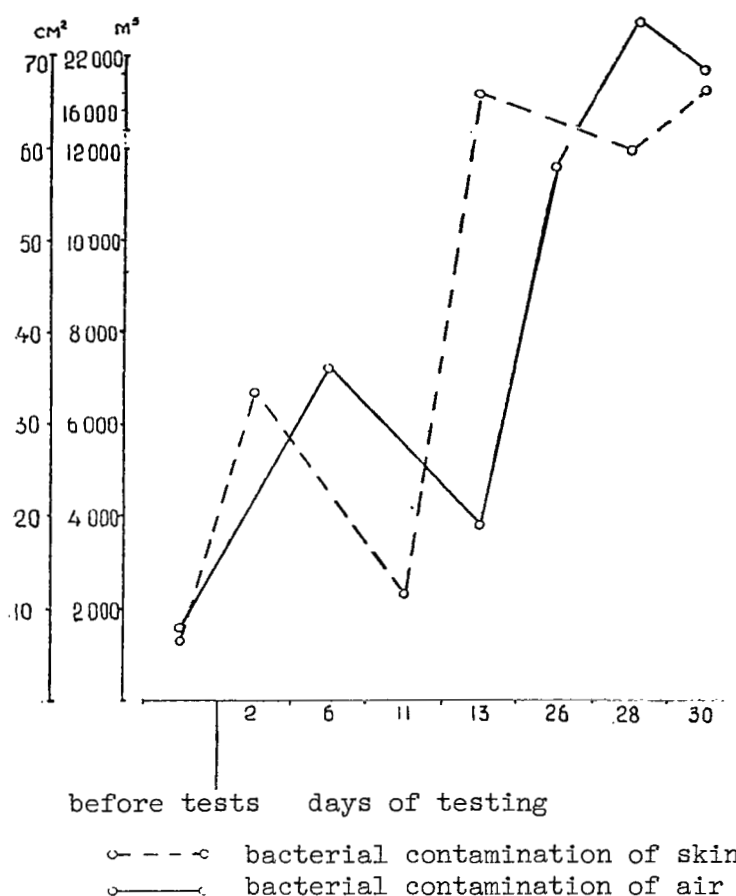


Figure 1. Comparative data on changes in the bacterial contamination of the skin and air

In the chamber experiments it was also found that in the absence of technical sources of CO in the chamber, the air medium is still contaminated with carbon monoxide, and that its source is man, in whose organism carbon monoxide is formed as a result of certain biochemical conversions which as yet have been insufficiently studied. By escaping from the organism and accumulating in the air, carbon monoxide causes the appearance of the initial symptoms of carbon monoxide autointoxication as a result of a decrease in the difference between its partial pressures in the exhaled air and in the air of the chamber. The auto-intoxication symptoms could be detected because of the appearance of carboxyhemoglobin in the blood and also the appearance of definite changes in the central nervous system (Figure 2).

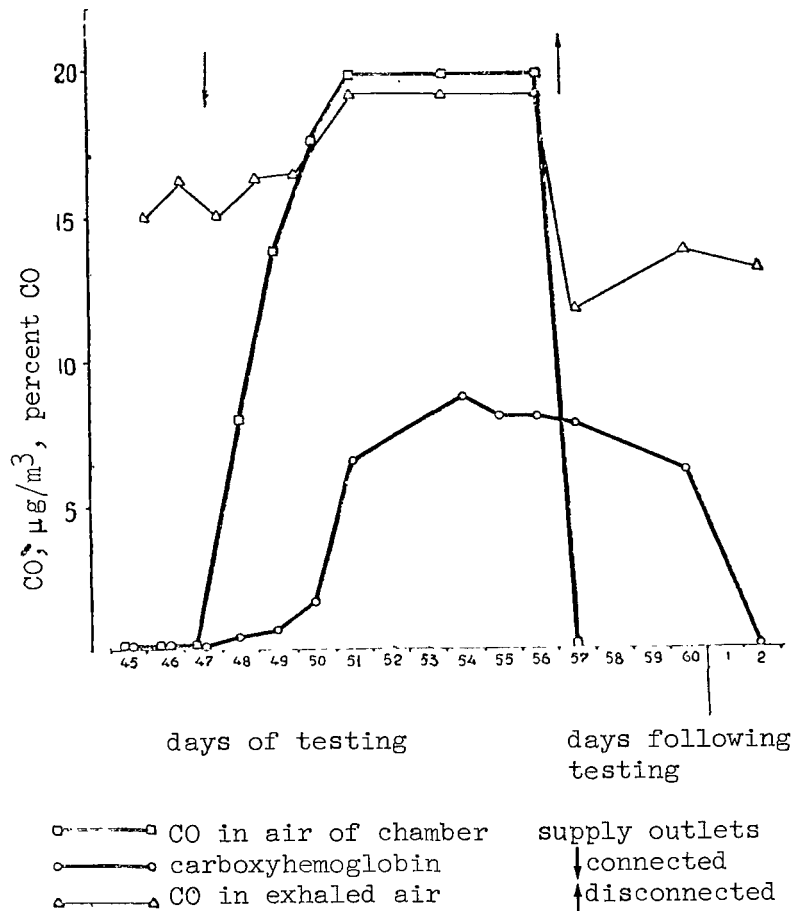


Figure 2. Dynamics of the carbon monoxide content in the chamber air, in exhaled air, and of the carboxyhemoglobin content in the blood of the subject

A similar dependence was found to be valid with respect to other substances which are evolved by the lungs, in particular, carbon dioxide. The carbon dioxide content in the air of the hermetically sealed chamber was an average of 0.4-0.6 percent during the tests, which was 10-20 times greater than its content in the atmosphere. As a result, the elimination of carbon dioxide through the lungs is hindered; the pressure of CO_2 in the alveolar air and in the blood rises; and this has

a definite effect on the function of external respiration and the gaseous interchange in tissues (L. R. Iseyev). This was particularly apparent in the 120-day tests.

Summarizing the above data, one is led to the conclusion that the cause of the many physiological changes which will be discussed below may be the autointoxication by the products of vital activity which are excreted through the lungs and which do not, under ordinary conditions, accumulate in the quantities observed in a hermetically sealed space with restricted volume.

In view of this fact, the maximum permissible concentration of such substances should be substantially below their content in the exhaled air, in order to avoid any interference with their normal elimination from the body. In particular, for carbon monoxide, we recommend an MPC of 3-5 mg/m³, and for carbon dioxide, in the case of confinement in sealed quarters for more than four months, 0.2-0.3 percent.

Autoinfection may also have a certain importance under these conditions. The role of allergens which may be present in the air medium and which form as a result of the vital activity of man has not been sufficiently studied.

Special relationships arising between the organism and the medium in a hermetically sealed space, as well as the influence of such factors as ionizing radiation, moderately high air temperature, and noise, coupled with the absence of ultraviolet radiation and the consequences of restricted motor activity must be considered. Thus, this complex of effects taking place in the majority of chamber tests cause the formation in the body of certain changes characterizing the reaction of the organism to changes in the life conditions. The most complete representation of the nature and mechanism of this reaction is given by the analysis of the physiological changes during periods of chamber tests of sufficiently long duration (60 and 120 days), in which the sequence of the appearance of these changes is particularly manifest.

During the first phase, which lasted about 10 to 15 days in 60-day tests, changes were observed which on the whole could be characterized as the initial reaction to the change in the life conditions. This reaction is related to the process of adaptation of the organism to the new functional level, which corresponds to a certain extent to the changed conditions. Toward the end of this period, there occurs a change in the regulatory mechanisms of the functions of blood circulation and respiration, i.e., those functions which largely determine the general functioning level of the organism.

By analyzing integral indices of the activity of the blood-circulating apparatus such as the systolic and minute volume of the heart, one can see that at rest their value decreased: the systolic volume decreased from 50 to 40 ml, and the minute volume from 3.75 to 2.7 l. When a graduated physical load was applied, these indices did

not reach the values which had been determined before the start of the tests in the chamber. At the same time, a delay in the normalization of this index was observed 3 minutes after the application of the load. The indicated changes should be regarded as a certain inertness of the mechanisms regulating the function of blood circulation (Figure 3).

From the standpoint of gas interchange, there was also observed (L. R. Iseyev) a certain inertness and irregularity of the mechanisms regulating this process. In graduated physical loading, the consumption of oxygen rose considerably and to a larger extent than before the start of the experiment. The process of liquidation of the oxidation debt was also appreciably delayed. Thus, the "efficiency" of the work decreased considerably.

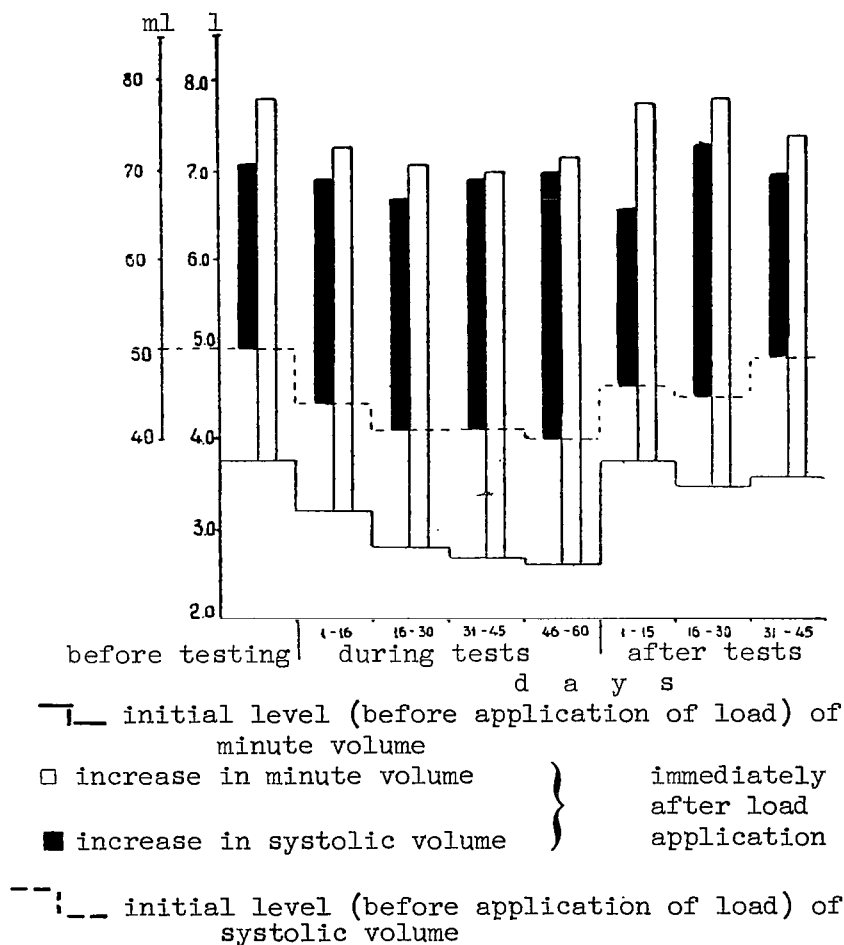


Figure 3. Change in systolic and minute volume of heart at rest and under physical load (average data of six subjects for every 15 days)

It is quite natural that these changes depend primarily on a unique accommodation of the regulatory mechanisms, most probably as a result of a change in the function in the CNS, one of the causes of which was the impairment of the habitual stereotype. During the initial period of the tests, the development of an inhibiting process was observed in the cerebral cortex (decrease of light sensitivity based on the data of adaptometry, increase in the time of motor reactions, etc.). This occurs most probably as a result of external retardation, and is associated with symptoms of a weakening of the process of internal retardation (increase in the number of errors during work, disturbance of night sleep, etc.). There are also some definite indications of certain changes in the activity of the endocrine system, especially an enhancement of the function of the adrenal cortex, which could be determined from a higher elimination of 17-ketosteroids with urine.

Despite the fact that the process of adaptation is associated with a number of unfavorable changes, the organism somehow adapts to the conditions of the changed medium of the sealed space. As a result, there takes place a certain normalization of many functions: sleep, motor reactions, light sensitivity of the eye, and the number of errors drops back down to the original values, etc. At the same time, enhanced fatigability persists. Thus, the adaptation is relative, and since the influence of unfavorable factors continues, there eventually occurs an impairment of the adaptive mechanisms, and asthenization symptoms are observed toward the end of the test.

In considering the physiological changes in the organism of the subjects tested, we use the term "asthenization." Indeed, a set of such phenomena as a reduced working capacity, enhanced fatigability, change in the sleep function, weakening of immunal reactivity, reduction in the functional potential of the cardiovascular system, decrease in the "efficiency" of physical work, and also very specific changes in the dynamics of cortical processes correspond to modern concepts of the asthenic syndrome. It is characteristic that a long time before the development of the external systems of asthenization, an impairment of the equilibration of nervous processes is observed in the cerebral cortex.

Of particular interest are the changes observed in the subjects upon their emergence from the chamber and transition to ordinary life conditions. We called these changes the "emergence reaction." It is primarily characterized by a certain deepening of asthenization, and the entire set of phenomena has a tendency to endure for a long time. Thus, after the 60-day tests, the state of asthenization remained for about 2 months. The mechanism of the creation of the emergence reaction apparently consists of the fact that as a result of prolonged human confinement in the chamber, there is formed a type of stable and fixed stereotype whose breakdown and replacement takes place with more difficulty

than does the adaptation to the conditions created in the sealed chamber, because the adaptive capacities of the organism themselves have been weakened by the prolonged influence of unfavorable factors in the course of the tests.

It should be emphasized that the transition from one set of life conditions to another is achieved in a very short time. For this reason, the less the life conditions in the sealed space differ from ordinary conditions, the less pronounced will be the emergence reaction. The experiments involving 120-day tests showed that the use of a set of sanitary measures (additional purification of air to remove bacteria and noxious chemical impurities, ultraviolet irradiation of the skin of the subjects, introduction of an increased amount of vitamins into the food ration, use of a special set of physical exercises and certain medicinal agents) during the following period as well as the organization of a gradual transition of the subjects from ordinary life conditions, promoted a considerable decrease in the intensity and duration of this reaction.

When the human organism is subjected to the simultaneous action of several factors of the medium, it is essential, from the practical standpoint, to know which factor is the most important, what is the role of the main factors, and which one should be considered first by a hygienist in the solution of problems pertaining to the improvement of the ambient medium. In addition, an analysis of the role of the acting factors makes it possible to elucidate such physiological regularities and the specificity of the reactions to the action, the phenomenon of summation of the effect of various stimulants, etc.

In our experiments, the human organism was subjected to the influence of factors arising during a prolonged confinement in a sealed space of limited size with the absence of ultraviolet radiation and a certain restriction of the motor activity, i.e., ionizing radiation in small doses, noise, raised air-temperature. It should be emphasized that the magnitude of most of the factors (concentration of CO_2 , CO and other noxious admixtures in the air, absorbed doses of ionized radiation, etc.) was close to the threshold values. Even the air temperature fluctuated around the permissible limits in the main experiments during a good part of the time. Under these conditions, a very important question is that of the possibility of formation of reactions which are specific for any of the acting factors, for example, for ionizing radiation. In analyzing the data obtained, we were unable to detect any specific reactions in the majority of cases.

Changes in such functions as the higher nervous activity, blood circulation, respiration, metabolism, etc., were not distinguished by any specificity and were an expression of the general reaction of the

organism to the unfavorable changes in the ambient medium. The presence of this nonspecificity led to the phenomenon of summation of the influences which differed in their nature. A sufficiently convincing example of such a summation is given below.

From the cited data (Figure 4), it is evident that as the testing conditions dependent on the inclusion of additional factors are accentuated, the rate of the motor reactions decreases (A. N. Kartsev). Whereas under optimum temperature conditions the reaction rate gradually increased owing to the training, when the air temperature rose to 40° - 47° , it dropped sharply at first and exceeded the initial value only toward the end of the tests. The inclusion of noise and ionizing radiation among the acting factors in other experiments led to a still more appreciable slowing down of the reaction, and its rate did not reach the initial values even at the end of the experiment.

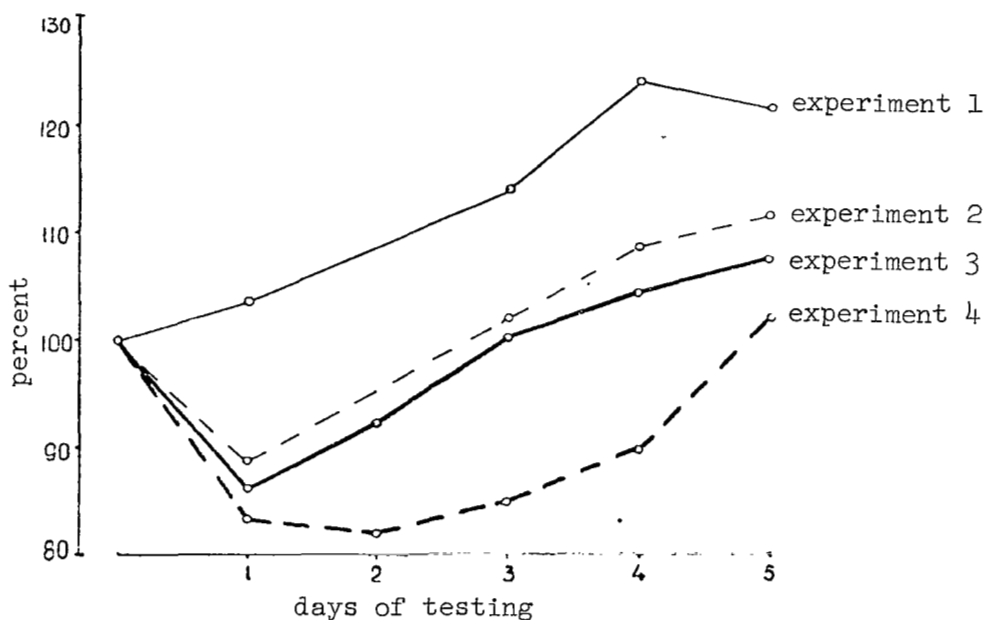


Figure 4. Dependence of the change in the motor reaction of "autorates" on the conditions of the tests (in percent of original): experiment No. 1, $T + 23^{\circ}$ C; experiment No. 2, $T + 40$ - 47° C; experiment No. 3, $T + 40$ - 47° C, noise, 105 db; experiment No. 4, $T + 40$ - 47° C, noise, 105 db, γ -irradiation $4.2 \mu\text{c/sec}$

The summation of the nonspecific influence of various stimulants appeared very distinctly in the analysis of daily human excretions of amino compounds in tests under various conditions. When ionizing radiation or intensive noise were included among the acting factors, the daily excretion of amino compounds in both cases increased by about 40 percent, but when both factors acted simultaneously, the excretions rose to 80 percent. It is obvious from the example that in certain cases the summation of the action of various stimulants may approach the absolute value, and factors which are different in nature may prove to be physiologically equivalent.

Nevertheless, against the general background of absence of specificity of reactions, in certain cases there appeared some changes which were characteristic of the action of a factor. An example is the appearance of carboxyhemoglobin in the blood and the presence of carbon monoxide in the air, and also an increase in the number of erythrocytes under these conditions. Of particular interest is the problem of the possible appearance of reactions which are specific for the action of ionizing radiation. An analysis of the blood picture (N. I. Suprunenko) has shown that in certain cases there may arise a specific depressing influence of ionizing radiation on leucopoiesis (Figure 5). However, this is observed only in the case where the dose of radiation exceeds 0.3 r/day and when its action is combined with the influence of such factors as noise and a raised temperature. In this case, the unfavorable factors potentiate the specific action of ionizing radiation. This phenomenon should be taken into account in the solution of the problem concerning the permissible radiation levels. In other words, the better the living conditions in the cabin of the spaceship, the greater the effect of ionizing radiation to which the astronaut can be subjected during the entire duration of his flight without risking any serious damage to his health.

A prerequisite for the summation of the physiological effect of several different stimulants is the simultaneity of their action. Their effect may be due precisely to their simultaneity, despite the fact that the intensity of each individual factor is close to threshold values. On the other hand, the unfavorable factors are acting constantly and for a long time. This results at first in the development in the organism of a certain relative adaptation, but it is also the cause of a gradual cumulation of the physiological effect, which causes an impairment of the adaptive and regulatory mechanisms and ultimately leads to asthenization. The phenomena of the cumulation of the physiological effect are also confirmed by the presence of a clear-cut dependence between the extent of the reactions and the duration of human confinement in the sealed chamber.

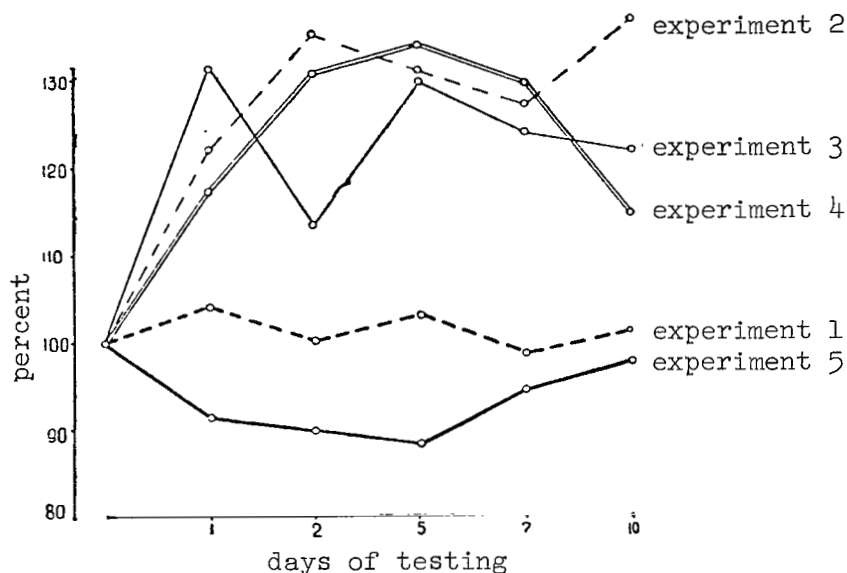


Figure 5. Dependence of the changes in the quantity of leucocytes on the experimental conditions (in percent of the initial level): experiment No. 1, without hermetic sealing, 0.3 r per day, $T + 28-34^{\circ}\text{C}$; experiment No. 2, with hermetic sealing, $T + 28-34^{\circ}\text{C}$; experiment No. 3, with hermetic sealing, 0.05 r per day, $T + 28-34^{\circ}\text{C}$; experiment No. 4, with hermetic sealing, 0.3 r per day, $T + 28-34^{\circ}\text{C}$; experiment No. 5, with hermetic sealing, 0.4 r per day, $T + 28-34^{\circ}\text{C}$. The experiment provides data on the first 10 days of a 15-day experiment

The answer to the problem of which of the factors acting on the human organism in the present experiment is the most important in the development of the above-described physiological changes was obtained by conducting different variants of the tests. It was found that the least pronounced changes associated with the action of ionizing radiation, raised temperature and noise, were observed in the case where the chamber was ventilated with external air. In this experiment, there were practically no changes in the blood and the cardiovascular system, and changes in the central nervous system were only very slightly expressed. Thus, one must recognize the fact that the external medium and, probably, primarily the chemical composition of the air which is formed in a sealed space of restricted volume, appeared to be the most essential factors affecting the human organism under such conditions.

Hence it follows that the creation of the most favorable conditions of "air livability" constitutes one of the most serious problems.

When man is confined to a sealed chamber, in addition to being subjected to the influence of purely physical factors dependent on his particular ambient medium, he is also subjected to the influence of factors of psychic order. Most important among these should be considered the forced isolation from the outside world, a disturbance of the customary situation, and finally, a definite monotony of the life conditions, accompanied by a considerable limitation of the incoming information. Acting through the second signalling system, they promote an appreciable development of the same physiological changes which were discussed above. In addition, there were observed some definite but weakly expressed deviations in the neuropsychic condition of the subjects. They included a higher excitability, as a result of which conflicts would arise somewhat more often than in an ordinary situation, and, in certain cases, a slight depression was noted. On the whole, however, the psychic condition of the subjects was wholly satisfactory, and the observed deviations did not have any serious effect on the course of the tests. This latter feature was due primarily to the fact that during the tests, such positive stimuli as a precise knowledge of the purpose and tasks involved in the tests, the feeling of responsibility for the assignment and the feeling of teamwork were acting. Another important point was the fact that while confined to the chamber, the subjects did some useful work most of the time. This not only minimized the deviations which were observed, but also corrected to a certain extent the development of such unfavorable neurosomatic reactions as asthenization.

In this connection, very interesting data were obtained by analysis of the periods of appearance of the changes as a function of the duration of the tests. Thus, according to the data of the EEG, changes in the central nervous system in the 10-day experiments were considerably more pronounced than during the first 10 days of the 2-month experiment, and, during the first month of the 4-month experiment, the EEG of the subjects was somewhat more stable than in the original background. As a rule, asthenization appeared only toward the end of the tests, regardless of their duration: 120, 60, 30, or 10 days. All this indicates the very important role of the "preparedness" for a given duration of tests, and the appreciable influence of the activity of the second signalling system on the autonomic functions of the organism as well.

Among the above-mentioned unfavorable factors, the monotony of the life conditions arising as a result of the standardization of the working, breathing and feeding conditions stands somewhat alone. This is because, even though the restriction of information does have an unfavorable effect, the standardization of the life conditions and a strict daily schedule have their positive side, particularly if it is

considered that all of the subjects were healthy young people. As a result of standardization of the life conditions, the subjects elaborated a new, forced stereotype of the occurrence of most physiological functions. In an analysis of the results of physiological investigations attention is drawn, not to the small individual differences, but primarily to the nature of the changes, common to all the subjects, taking place in the majority of the functions. This stereotype character is outlined with particular clarity during the analysis of the data on the working capacity and fatigue processes. Changes of these indices in individual subjects differ somewhat, but only in degree, and as far as their direction and period of appearance are concerned, they were the same in all the subjects. At the present time, we cannot say whether this standardization of the reactions of the subjects is favorable or not; it can only be described as a characteristic physical phenomenon illustrating the strict dependence of the function of the organism on the conditions of the ambient medium.

It should not be thought, however, that this stereotype of the reactions excludes some individual characteristics of the subjects. Individual differences depend on whether or not the subjects participate in such experiments for the first time. These differences are particularly evident in the analysis of the dynamics of weight change and also in the analysis of the indices of nonspecific immunity. It should be emphasized that in persons who had earlier participated in chamber tests, the majority of the reactions usually took place with lesser changes.

The existence of individual differences both in the higher nervous activity and in the autonomic functions of the participants in such types of tests make it necessary to concentrate attention on the compatibility of several people who must live and work together for a long time in a restricted space isolated to a considerable extent from the world outside. To date, attention was primarily concentrated on the problem of psychic compatibility: what should be the character traits of the individual members of the crew which, when combined, would be least likely to produce serious conflicts. Work in this direction is undoubtedly important, but not enough significance has been attached to the interaction of the individuals via the second signalling systems, which affect the character traits of each. We therefore consider it valid to pose the problem of the "biological" compatibility of the individuals on a broad biological plane.

As was repeatedly stated above, the medium of sealed quarters is formed as a result of the vital processes of the man who is confined to them for a long time. Consequently, individual differences in the metabolism of different people will have different effects on the quantitative and qualitative composition of the volatile components involved into the air of the sealed quarters in the course of breathing, and from the surface of the skin. Similarly, the qualitative and quantitative

composition of the microflora in the air of the sealed quarters will depend on the individual differences of the autoflora. These points obviously far from exhaust all the aspects of the problem of biological compatibility. However, even in these problems our knowledge is utterly insufficient.

The only thing which we now know is the difference in the qualitative and quantitative composition of the autoflora. As far as the qualitative and quantitative composition of the exhaled air, sweat, and certain other volatile human excretions are concerned, this problem has not been solved. Nevertheless, there is nothing we can say on the basis of these indices concerning the mutual influence of individuals with different individual characteristics. Considerable research is required in this field, and it is our opinion that space medicine cannot remain idle in the solution of this problem.

Translated for the National Aeronautics and Space Administration
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